

# DIGITAL TRANSFORMATION & SUSTAINABLE SUPPLY CHAINS: EXPLORING INDUSTRY 4.0 FOR ENHANCED PERFORMANCE

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## **Abstract**

### **Purpose**

This paper aims to explore the relationship between sustainable supply chain management and digital transformation. It also aims to develop a conceptual framework, which clarifies under which circumstances the above combination could lead not only to increased business performance, but also to the development of specific sustainable strategies.

### **Design/Methodology/Approach**

The research follows a mixed methodology, involving a combination of a quantitative and qualitative approach. The quantitative research was based on a survey conducted in 3PL (third party logistics) companies. The collected data enabled the testing and verification of specific hypotheses and led to conclusions that were further explored through qualitative research. The qualitative research was based on the analysis of three case studies leading to an in-depth understanding of the research questions and findings.

### **Findings**

The main findings of this paper demonstrate that digital transformation plays a critical role for companies, as integrating various technologies with business resources can lead to the development of key supply chain capabilities that enhance both sustainability impact and business performance. Furthermore, the results underscore the potential for companies to further advance their sustainability strategies through digital transformation.

### **Originality/Value**

This paper contributes to the literature by addressing a gap in the exploration of all three pillars of sustainability within supply chains, particularly in relation to the impact of information systems and new technologies. It also addresses the lack of mixed research methodologies in this field by developing a theoretical conceptual framework that underpinned the empirical work. The research findings emphasize the importance of digital transformation in fostering sustainable supply chain practices and offer a foundation for further investigation in different industries and company types.

### **Research limitations/implications**

The quantitative research was conducted only in 3PL companies, while the qualitative research was conducted in three companies with different roles (manufacturer, 3PL and retailer) in the supply chain. Therefore, to attain more detailed conclusions, the paper proposes the expansion of this research to include more companies and industries.

## **Keywords**

Digital Transformation, Sustainable Development, Supply Chain Management, Industry 4.0, Business Performance

## **Introduction**

In recent years, the adoption of new information technologies has significantly contributed to the digital transformation (DT) of companies, enhancing and optimizing their operations. Verhoef et al. (2021) note that companies embracing digital transformation have outperformed many traditional businesses. Despite the evident impact of DT on improving business performance, academic attention has been limited, with research into digitization and digital transformation only beginning to rise a few years ago.

Modern companies, which are part of large supply chains need to use new technologies or information systems (IS) to optimize their operations and improve collaboration with trading partners (Rinaldi *et al.*, 2021). DT has the potential to convert traditional supply chains into efficient and intelligent supply chains by connecting all functions and processes, such as product design and production, procurement, logistics, product distribution and customers' services (Brettel *et al.*, 2014).

In addition to the emergence of new technologies and the digitalization of supply chains, sustainability has become a focal objective for many companies. This shift is driven by the growing emphasis placed by organizations like the United Nations and the European Union not only on environmental issues, but also on societal well-being. As a result, companies need to prioritize the development of socially and economically sustainable supply chains, considering the interests of all stakeholders in

their operational environment. Integrating digitalization with sustainable practices within digital supply chains will benefit every participant involved (Farahani et al., 2017).

To address the above issues, this paper examines related research, identifies research gaps in the literature and develops a conceptual framework to explain the relationship between digital transformation and sustainable development. The results of this study, based on a mixed research methodology (qualitative and quantitative), are consistent with the findings of previous research (Stroumpoulis *et al.*, 2021) and show how the combination of sustainable policies with IT and SCM resources can lead to increased business performance and sustainable impact.

### **Theoretical Development**

Researchers, academics, practitioners and business associations are highly interested in understanding the impact of digital transformation (DT) on societal processes, products, and business models (Al-Emran and Griffy-Brown, 2023). It is suggested that without the effective development and implementation of information technology (IT), the business world and society will struggle to achieve the sustainability goals set for 2030.

According to the literature, IT is the most critical factor enabling companies to undergo digital transformation (DT) (Andriole et al., 2017). Therefore, DT is closely linked to the application of IT within companies, with the potential to increase productivity and reduce operating costs (Yin, 2023). While it is commonly believed that digitization refers to the adoption of new digital technologies (Fitzgerald et al., 2014), this research supports the concept of DT as the use of IT resources to enhance a firm's business capabilities.

IT also plays an important role in supply chain management (SCM), as it is imperative for the development of an effective supply chain (de Camargo Fiorini and Jabbour, 2017). According to Kagermann et al. (2013), IT can fully unlock the value and efficient operation of a supply chain if all partners and their customers are able to cooperate and exchange information effectively. Therefore, achieving alignment among all trading partners is crucial when adopting new technologies to foster effective collaboration (Moeuf et al., 2018). The development and alignment of the IT infrastructure are equally important for the operational efficiency of the supply chain members. However, aligning IT among partners is challenging and requires a commitment of resources and coordination at all stages of the chain. Despite these challenges, IT alignment is essential, as digitizing supply chains can lead to automated processes within companies, saving time and resources, redistributing roles, and ultimately increasing performance and productivity (Schallmo et al., 2017).

Also, IT is a very important factor in achieving environmental sustainability (Wang *et al.* 2015). While IT affects the financial, operational, and environmental performance of companies, it remains unclear how its use in sustainable supply chain management (SSCM) might affect the resulting social performance (Fiorini and Jabbour, 2017).

Finally, according to Shee *et al.* (2018), when IT has a positive impact on supply chain performance, it can also improve the sustainable performance of the member companies.

### **Research gaps**

This research aims to address the gaps identified in the literature by developing a conceptual framework and analysing the three pillars of sustainability. The literature review revealed certain research limitations. Firstly, although sustainable SCM is aligned with the three pillars of sustainable development, not all pillars are adequately addressed or framed in existing literature review. Mani *et al.* (2016) highlight that the social dimension of sustainable SCM receives the least attention, yet its integration is crucial for companies to achieve true sustainability. Similarly, Birkel and Muller (2021) point out that Triple Bottom Line (TBL) approaches and the application of information technologies in supply chains are predominantly focused on financial outcomes, neglecting the environmental and social pillars. The literature review indicates that a few studies analyse the integration of all three dimensions. Regarding new technologies of DT, such as blockchain technology (BT), could support supply chains by serving as a decision-making tool. It could help managers enhance their social pillar by aligning with partners and reducing fraud, while also contributing to the environmental pillar by managing and reducing waste in specific industries, such as tourism. However, there is a lack of studies in the literature that explore its impact on sustainability practices within supply chains (Saberi *et al.*, 2019). The same gap exists concerning the use of the Internet of Things (IoT) in supply chains. The implications of IoT are still in the early stages within the supply chain industry (Manavalan and Jayakrishna, 2019), and only a limited number of studies suggest that IoT could improve sustainable SCM and enhance supply chain performance (Manavalan and Jayakrishna, 2019).

After reviewing the relevant papers, none has developed a comprehensive, conceptual framework that addresses the gaps in TBL and digital technologies, nor have they examined the new

technologies of Industry 4.0 and their contributions to supply chains (Stroumpoulis and Kopanaki, 2022).

### Conceptual Framework

The literature review identified key factors related to the topic of study and demonstrated that integrating sustainable development and DT with supply chain management (SCM) and IT resources, along with specific IT-based capabilities, can affect both a company's business performance and sustainable impact.

To better understand and explain this sustainable impact, particularly the economic, environmental, and social impact, theories such as the "natural resource-based view," "stakeholder theory," "legitimacy theory," and "transaction cost theory" were identified and served as the foundation for developing the conceptual framework that underpins this study. The application of the N-RBV theory in SCM offers a comprehensive approach to understanding how firms can use natural resources strategically to gain competitive advantages while addressing environmental concerns. This theory highlights the importance of integrating sustainable practices into SCM strategies, which is essential for assessing the environmental impacts of these activities (Joshi & Li, 2016). Stakeholder and Legitimacy theories, when integrated into SCM, provide a robust framework for understanding and managing the social impacts of supply chain activities. These theories emphasize the importance of considering stakeholder perspectives and ensuring that business practices are perceived as legitimate by various stakeholders, including employees, communities, and consumers (Ali & Rizwan, 2013; Deegan, 2019). The Transaction Cost Theory (TCT) offers a powerful framework for analysing the economic aspects of SCM. This theory focuses on the economic factors that influence relationships between business partners within supply chains, such as the costs associated with contracting, managing, and coordinating these relationships. By applying TCT, the research can assess the economic impact of various SCM practices, including contract management and market trend analysis. TCT also helps identify opportunities for cost reduction, risk mitigation, and value creation (Mahapatra *et al.*, 2010).

Moreover, based on the literature review, specific hypotheses have been developed.

- *H1: The company's focus on Digital Transformation (V02) and the orientation towards Sustainable Development (V06) positively influence the development of Capabilities (V05).*
- *H2: The level of Information Technology (V04) together with the skills of the Human Factor (V03) positively influence the development of Capabilities (V05).*
- *H3: The Supply Chain Processes (V01) together with the focus on Digital Transformation (V02) positively influence the development of Capabilities (V05).*
- *H4: The capabilities (V05) that have emerged from the supply chain environment improve the sustainable impact (V11) that have resulted from the adoption of sustainable practices.*
- *H5: The capabilities (V05) that have arisen from the use of Information Technology lead to an increase in Business Performance (V07).*
- *H6: The sustainable impact that has resulted from the use of Information Technology (V11) leads to Excellence in Sustainable Development (V08) within the industry.*
- *H7: The sustainable impact derived from the use of Information Technology (V11) leads to Digital Transformation Excellence (V09) within the industry.*
- *H8: The resulting Business Performance (V07), Excellence in Sustainable Development (V08) and Digital Transformation (V09) lead to the development of Sustainable Strategies (V10).*

The conceptual framework, depicted in Figure 1, demonstrates how companies can leverage sustainable policies and IT resources to improve process effectiveness and efficiency, addressing the above hypotheses. By integrating IT and SCM resources with an emphasis on sustainable development and DT, companies can achieve IT-related business capabilities that lead to improved business performance and sustainable outcomes, promoting excellence in these areas. Ultimately, these capabilities enable companies to further develop sustainability strategies, thereby improving their position in the market. As a result, the integration of digital technologies with sustainability objectives contributes to creating a more responsible and resilient business environment (Gupta *et al.*, 2020).

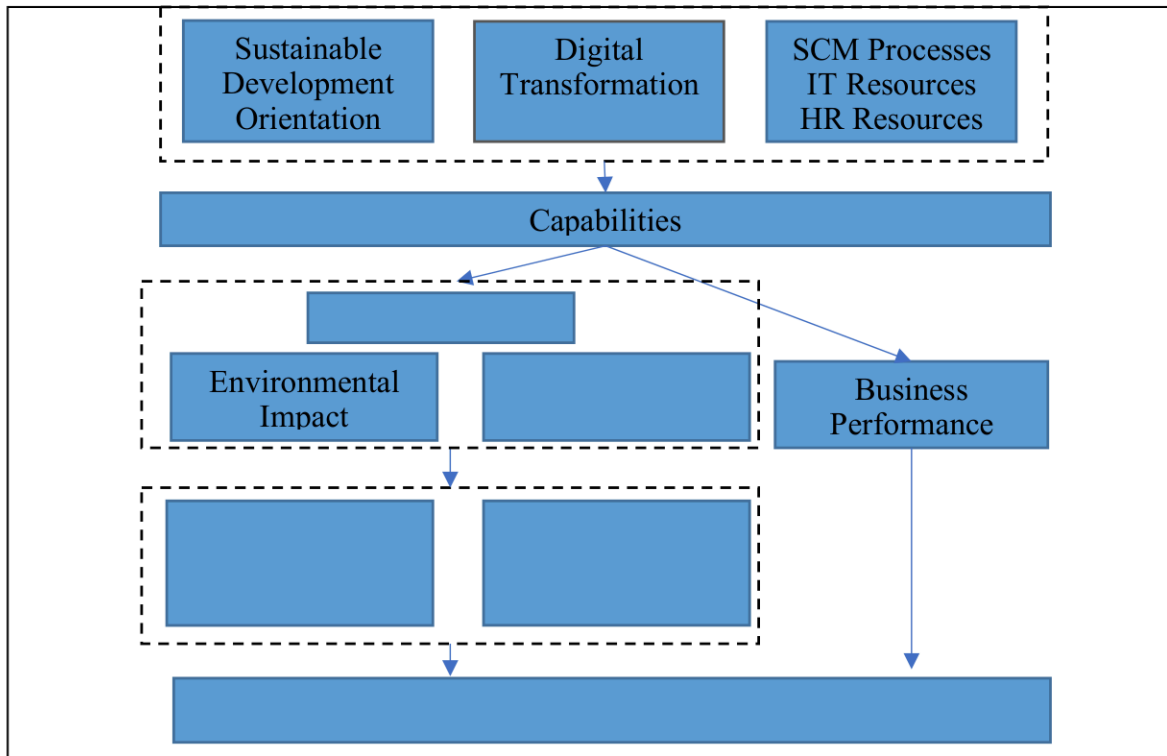


Figure 1: Conceptual Framework  
Source: Stroumpoulis *et al.*, 2024

### **Research Methodology**

In this research, a mixed research methodology was used in order to understand and address appropriately its purpose and objectives. Initially, quantitative methodology was carried out by using and designing a survey questionnaire. Finally, qualitative research through case study analysis was conducted with the use of semi-structured interviews. The combination of all the above was carried out to draw more reliable conclusions.

### **Quantitative Methodology**

To reach safe conclusions, the authors used and tested the above conceptual framework through empirical work. To achieve this, they first employed a quantitative methodology, which investigates phenomena by collecting quantifiable data in numerical form and applying mathematical models and statistical techniques to analyze the data (Creswell and Poth, 2016). Questionnaires play a crucial role in quantitative methodology as a data collection tool (Caputi and Balnaves, 2001).

The questionnaire was formulated in accordance with the above theoretical framework, but also with the research hypotheses developed to better understand the framework. For the realization of the research, it was deemed necessary to involve the participation of the "3PL" companies that exist and operate in Greece. The industry of 3PL companies was chosen as these companies can contribute significantly not only to the economic, social and operational performance, but also to the environmental performance of their supply chain.

Following a search conducted both through the search engine "Google" and a sectoral study, a total of 251 companies were recorded, of which 111 are located in the Attica Region. In the specific research that was conducted, a total of 67 companies participated. Therefore, the response ratio of the survey is approximately 27%, which is acceptable, because according to Leslie (1972, p. 332), when the sample is homogeneous then "...surveying issues directly related to homogeneous groups should not be overly concerned about the percentage of questionnaire returns.". Moreover, the survey which was conducted by Sheekan *et al.* (2001) revealed that there is a huge decline in the response rate through email from a mean response rate of 61.5% to 24.0% in 2000. The above statement is confirmed by the survey of Wu *et al.* (2022), which observed that surveys with a smaller sample size (i.e., less than 500) require response rates of 20% to 25% to generate reasonably confident estimates.

The variables that emerged from the questionnaire were too many, so it was necessary to group them together in order to better study the research hypotheses. In order to reduce the number of variables, factor analysis was carried out using the statistical software SPSS (IBM) (Field, 2009). The above method describes the analysis of variability among correlated variables, while reducing their number

to a group of factors, also known as factors (Tharenou *et al.*, 2007). Specifically, Factor Analysis is a multivariate technique, which is undertaken to reduce the observed variables (Yong and Pearce, 2013). A Kolmogorov-Smirnov analysis was also necessary to examine whether the variables could follow the normal distribution. The KS test is widely regarded as one of the most well-known normality tests. It is mainly used to determine whether a sample originates from a population with a completely specified continuous distribution. (Drezner *et al.*, 2010). According to Sainani (2012), if the dependent variable follows the normal distribution, then the statistic test of linear regression is appropriate in order to test the hypotheses. Therefore, the linear and multiple regression analysis took place and confirmed that all the hypotheses of this research were supported.

Hypothesis	Findings	Formula
H1	Accepted	$(V05) = 0,875(V02) + 0,760(V06)$
H2	Accepted	$(V05) = 0,793(V03) + 0,684(V04)$
H3	Accepted	$(V05) = 0,694(V01) + 0,822(V02)$
H4	Accepted	$(V11) = 4,036(V05) + 21,574$
H5	Accepted	$(V07) = 0,408(V05) + 2,048$
H6	Accepted	$(V08) = 0,027(V11) + 2,972$
H7	Accepted	$(V09) = 0,027(V11) + 3,105$
H8	Accepted	$(V10) = 0,524(V07) + 0,515(V08) + 0,462(V09)$

Table 1: Quantitative analysis results

### Qualitative Methodology

For the qualitative research, a case study methodology was selected. The research aimed to examine whether integrating sustainability orientation with IT and SCM resources in specific business contexts could improve sustainable impact and strategy formulation within the supply chain. To thoroughly explore this phenomenon and contribute to theoretical advancements, a multiple case design approach was employed. The cases were chosen using a non-random sampling strategy (Saunders *et al.*, 2019) and included a 3PL company, a retailer and a producer of building materials. In this way, the supply chain was examined from different perspectives allowing a better understanding of the issues under consideration. To ensure effective data collection, the study adopted an approach combining documentation analysis, semi-structured interviews, and participant observations. This comprehensive method was designed to gather data from various sources, enabling data triangulation (Shih, 1998). The results obtained from the empirical data collection are summarized in the following table:

Codes	3PL	Retailer	Producer
Sustainable Development Orientation	<ul style="list-style-type: none"> <li>• Photovoltaic unit installation</li> <li>• Electric vehicles</li> <li>• Specialised staff</li> <li>• Continuous staff training</li> <li>• Close collaboration with business partners</li> <li>• Energy neutrality investments</li> </ul>	<ul style="list-style-type: none"> <li>• Recycling</li> <li>• Environmental campaigns</li> <li>• Circular economy</li> <li>• Packaging improvement</li> <li>• Social contribution</li> <li>• Staff education and awareness raising</li> <li>• Close collaboration with business partners</li> <li>• Energy neutrality investments</li> </ul>	<ul style="list-style-type: none"> <li>• Circular economy</li> <li>• Reduction of CO2 emissions</li> <li>• Reduction of production resources' consumption</li> <li>• Marine biodiversity protection</li> <li>• Social contribution</li> <li>• Health &amp; safety of employees and partners</li> <li>• Continuous training</li> <li>• Close collaboration with business partners</li> <li>• Resilience to Economic challenges</li> </ul>
IT & Digital Transformation	<ul style="list-style-type: none"> <li>• Warehouse Management System</li> <li>• Process automation using Barcode</li> </ul>	<ul style="list-style-type: none"> <li>• Internet of Things</li> <li>• Warehouse Management System</li> <li>• Telematics</li> <li>• Transportation Management System</li> </ul>	<ul style="list-style-type: none"> <li>• ERP (Financial Supply Chain Management; Logistics Execution)</li> <li>• Internet of Things</li> <li>• Big Data Analytics</li> </ul>
SCM Resources/ Processes	<ul style="list-style-type: none"> <li>• Warehouse management</li> <li>• Picking &amp; packing</li> </ul>	<ul style="list-style-type: none"> <li>• Fleet management</li> <li>• Mapping Systems for route optimization</li> </ul>	<ul style="list-style-type: none"> <li>• Fleet management</li> <li>• Electric vehicles for products' transportation</li> </ul>

	<ul style="list-style-type: none"> <li>•New facilities in northern Greece</li> </ul>	<ul style="list-style-type: none"> <li>•Warehouse layout</li> <li>•Cameras and sensors</li> <li>•Distribution infrastructure</li> </ul>	<ul style="list-style-type: none"> <li>•Location and traffic assessment for distribution centers</li> <li>•Upgrading and modernization of facilities</li> </ul>
Capabilities	<ul style="list-style-type: none"> <li>•Efficient warehouse management</li> <li>•Automation</li> <li>•Customer satisfaction and "Loyalty"</li> </ul>	<ul style="list-style-type: none"> <li>•Productivity increase</li> <li>•Reduction of operating costs</li> <li>•Consumer value</li> </ul>	<ul style="list-style-type: none"> <li>•Process automation</li> <li>•Efficient management of distribution centres</li> <li>•Consumer value</li> </ul>
Environmental Impact	<ul style="list-style-type: none"> <li>•Reducing the environmental footprint</li> <li>•Reverse Logistics</li> <li>•Traceability</li> </ul>	<ul style="list-style-type: none"> <li>•Environmental footprint reduction</li> <li>•Paperless processes</li> <li>•Reverse logistics</li> <li>•Traceability</li> </ul>	<ul style="list-style-type: none"> <li>• Environmental footprint reduction</li> <li>•Responsible resource management</li> <li>•Waste reduction</li> </ul>
Social Impact	<ul style="list-style-type: none"> <li>•Alignment with business partners</li> <li>•Transparency</li> <li>•Equal opportunities</li> </ul>	<ul style="list-style-type: none"> <li>•Transparency</li> <li>•Corporate Social Responsibility</li> </ul>	<ul style="list-style-type: none"> <li>•Transparency</li> <li>•Safety</li> <li>•Corporate Social Responsibility</li> </ul>
Economic Results	<ul style="list-style-type: none"> <li>•Financial resources saving</li> </ul>	<ul style="list-style-type: none"> <li>•Financial resources saving</li> <li>•Research funding</li> </ul>	<ul style="list-style-type: none"> <li>•Cost savings Access to green finance</li> </ul>
Sustainable Development Excellence			√
DT Excellence		√	
Business Performance	√	√	√
Sustainable Strategies	<ul style="list-style-type: none"> <li>•Strategy for the development of sustainable competences and skills</li> <li>•Sustainability strategy based on economic incentives</li> </ul>	<ul style="list-style-type: none"> <li>•Strategy for the development of sustainable competences and skills</li> <li>•Sustainability strategy based on economic incentives</li> </ul>	<ul style="list-style-type: none"> <li>•Networking strategy</li> <li>•Marketing and promotion strategy for sustainable products</li> <li>•Sustainable technological development strategy</li> </ul>

Table 2: Overview of findings across different companies  
Source: Stroumpoulis *et al.*, 2024

### **Conclusions and Limitations**

The mixed methodology used in this study provides a comprehensive and insightful understanding of the intersection between IS, DT and Sustainability in SCM. The quantitative analysis confirms all the research hypotheses developed, aligns with previous literature and highlights the significant potential of DT to enhance sustainability in supply chains. This quantitative perspective reinforces the critical role of IS in improving business processes and fostering sustainability-oriented practices. Moreover, it highlights the connection of the three pillars of sustainable development - economic, environmental and social - demonstrating that investments in IT and human capital can lead to the development of Capabilities. Also, the sustainable impact developed will lead to excellence in DT, Sustainable Development and, combined with increased Business Performance through Capabilities, will lead to new sustainable strategies.

The qualitative findings from the case studies complement the quantitative analysis, revealing a common thread among companies that prioritize sustainability in their core activities. These companies, regardless of size or industry, recognize the necessary role of IS and DT in enabling and supporting their sustainable strategies. They have adopted an integrated approach that takes into account the economic, environmental and social dimensions of sustainability, thus creating value on multiple fronts. Through innovation and investment in DT, these companies have reduced their environmental footprint, improved operational efficiency and enhanced social impact. Importantly,

these sustainability efforts have not only contributed to environmental and social improvements, but have also yielded economic benefits, highlighting a long-term commitment to sustainable growth over short-term profits. In essence, these companies are well positioned for excellence in their industries, highlighting the importance of IT and sustainability strategies in shaping the future of SCM.

There are also some important limitations, which will have to be addressed in a subsequent study in order to obtain generalized and reliable conclusions. First, the questionnaire could be sent to other supply chain sectors in order to collect more data. In addition to the additional sectors, a survey could also be conducted in other countries. In addition, the qualitative research could include more case studies in each of the sectors. Again, companies from different countries with similar characteristics could be included. Finally, in addition to the range of companies and industries, a future survey could focus on the study of new technologies that are constantly emerging.

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